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Simultaneous growth releases and reductions among *Populus alba* as an indicator for floods in dry mountains (Morocco)

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ABSTRACT

We studied the growth reaction of silver poplar trees (*Populus alba*) to a large flood in November 2014 in the semi-arid High Atlas Mountains, Morocco. The flood resulted in half of the studied trees developing wider tree rings in 2015 and the other half developing narrower rings in 2015, next year after the flood. For 57.1% of trees which released growth in 2015, this was the most significant increase of ring width during their whole lives (in whole tree-ring chronologies), and for 23.8% of trees which reduced growth in 2015, this was the most significant decrease of ring width. Tree-ring reductions in next year after the 2014 flood resulted from environmental stress related to burying stems with alluvia deposited during the flood. Fresh sediments cut off air access from the root system, and for some of the sampled trees, this stress was strong enough to control their radial growth. Growth releases that follow the 2014 flood are a record of trees benefitting from a sudden supply of water, a rare opportunity in dry study area, where water is usually scarce. The study demonstrates that floods in high mountains of arid zone can cause dual, opposite growth reaction of affected trees. Such dual record is characteristic for environmental impulses, which exert stress on trees, but, at the same time, improve other conditions of tree growth. Environmental events that cause simultaneous positive and negative reactions among a population of trees, like studied flood, can easily be overlooked in chronologies based on average widths of tree rings each year. For trees affected during studied flood arithmetical mean of ring widths in 2015 is average and does not stand out from arithmetical means for other years. However, when analysed in detail, the year 2015 is significantly different from other years, as is demonstrated by high values of dispersion indicators (standard deviation and coefficient of variation) calculated for all sampled trees. This study demonstrates that following the standard procedure (developing tree-ring chronology from average ring widths) is not a reliable solution for reconstructions of environmental impulses which cause dual, opposite reaction among sampled trees. Even strong events of this type will not be emphasised in standard chronologies, which can lead to underestimating frequency and magnitude of processes and, in the case of floods, to underestimating hazard and risk.

1. Introduction

Trees can record various environmental factors as growth disturbances in their tree rings and wood anatomy (Schweingruber, 1996). Factors influencing radial growth of trees can vary in strength, ranging from small impulses (Koprowski et al., 2018; Edvardsson et al., 2019; Sun and Liu, 2019), to significant environmental changes are recorded in the tree rings (Camarero et al., 2015; Zhang, 2015; Sánchez-Salguero et al., 2017). Environmental factors affecting trees also differ in their spatial range. They vary from local ones, occurring only in relatively small areas, like coastal storms or debris runoff routes (Arbellay et al., 2010; Pouzet et al., 2018) to factors operating over vast areas, like air pollution (Kandler and Innes, 1995; Elling et al., 2009). Depending on the strength and spatial range of environmental factors, their record in tree rings is very different. Strong impact commonly causes radial growth to stop, which manifests as missing rings on a stem cross-section

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(Wilmking et al., 2012). Weaker environmental factors result in more gentle disturbances of tree growth, like slightly eccentric tree rings (Malik et al., 2016; Wistuba et al., 2018).

Disturbances of radial growth are fundamental dendrochronological indicators of changes in environmental conditions. When tree growth conditions improve, the width of newly developed increments increases compared to increments formed before. Such abrupt growth releases are formed for example by trees which survived an event that eliminated other, adjacent specimens: a wildfire (Py et al., 2006), a landslide (Šilhán, 2015) or forest thinning (Niukkanen and Kuuluvainen, 2011). When environmental conditions worsen, trees develop reduced tree rings (Schweingruber, 1988). There are many environmental factors which can cause long-term ring reductions, for example, insect outbreaks (Weber and Schweingruber, 1995), air pollution (Malik et al., 2012) or volcanic eruptions (Salzer and Hughes, 2007).

However, environmental factors often overlap (Pohl et al., 2006). More than one factor can influence a tree simultaneously; for example, one tree can be affected by air pollution and by landslide activity of bedrock at the same time. In such case, both environmental factors are recorded in the same sequence of tree rings and determining factor responsible for a particular pattern of ring widths is a major issue of dendrochronology (Malik et al., 2014). Moreover, one environmental impulse can, at the same time, exert different force and type of impact on different groups of trees, depending on spatial variability of the impulse or on features of trees, such as age, health conditions, social status or species. As a result, trees can even produce opposite reactions to the same impulse, e.g. tree-ring reductions and tree-ring releases. A wildfire can strongly injure some trees, which start to develop reduced tree rings (Brown and Swetnam, 1994; Seifert et al., 2017). At the same time, less injured or uninjured trees start to develop wider rings as they benefit from improved light conditions after the wildfire eliminated adjacent trees (Py et al., 2006). During harmful emissions of pollutants into the atmosphere, some trees die (Pope, 2007) and, after the pollution stops, surviving specimens develop wider tree rings (Malik et al., 2012). Thus, even long-term emission of pollutants into the air can cause different reactions of trees: tree-ring reductions and releases. Opposite growth reactions have also been described in dendrochronological studies of trees growing on active landslides (Malik and Wistuba, 2012; Malik et al., 2016; Šilhán, 2017). Dendrochronological dating and reconstruction of landslides is often based on eccentric tree growth resulting from the tilt of tree stems due to ground movement. Tilted tree develops narrower tree rings on one side of the stem and wider rings on the opposite side of the stem (Wistuba et al., 2013, 2019; Šilhán and Stoffel, 2015; 2021). Floods are also one of the environmental factors which can be recorded in tree rings, and dendrochronology is used to estimate flood age and frequency since the 1960s (Sigafoos, 1961; 1964;; Harrison and Reid, 1967; Stewart et al., 1967; Everitt, 1968; Alestalo, 1971). Various dendrochronological indicators can be applied for this purpose (Ballesteros-Cánovas et al., 2015a), such as: (1) the age of trees from alluvial surfaces formed during different floods, (2) reaction wood and ring eccentricity caused by tilting of trees on eroded river banks (Hupp and Osterkamp, 1996), (3) scars left on stems and roots after wounding by debris transported during floods (Tardif and Bergeron, 1997; Zielonka et al., 2008), (4) sprouts developed after wounding or tilting (Sigafoos, 1964; Malik, 2006), (5) changes in the size of vessels in deciduous trees (Arbellay et al., 2012b), (6) traumatic resin ducts in coniferous trees (Schneuwly et al., 2009; Bollschweiler et al., 2008), (7) tree roots exposed by erosion during floods (Stoffel and Wilford, 2012) and related changes of their wood anatomy (Gärtner et al., 2001; Gärtner, 2007; Malik, 2008; Malik and Matyja, 2008).

Wide application of dendrochronology in flood analyses, including the potential application in hazard studies, makes the accuracy of tree-ring analyses a crucial issue. Therefore, it is also vital to recognise a detailed tree-ring record of floods, including potential sources of misinterpretations, including the opposite reaction of different groups of trees. Floods in arid areas are a good example of the latter issue. In this study, we assume that their impact of tree growth is unique and can act in two ways. Floods exert stress on tree growth through inundation, injuries by transported debris and burying stems by fresh deposits. On the other hand, floods deliver water, scarce in arid areas, which positively affects vegetation. This study aimed to identify the dendrochronological record of large floods affecting trees in high-mountain valleys of the dry zone. We aimed to determine changes of tree-ring widths and establish unique tree-ring patterns developed due to floods by trees growing in high mountains of the arid zone. We also aimed to check if dual, opposite, positive and at the same time negative, impact of floods on trees is reflected in their tree rings.

2. Study area

The study was conducted in the basin of perennial Dadès River in Morocco (Fig. 1). Sources of Dadès are located at 3313 m a.s.l in the south-central High Atlas Mountains. Through its extension, Drâa River, Dadès flows into the Atlantic Ocean forming the longest river system of Morocco (1300 km). The study area is located in semi-arid mountain catchment (1525 km^2) of Upper Dadès River (132 km, 1526–3313 m a.s.l) (Dłużewski et al., 2013). The study focuses on two study sites (DAD1 (31.435381° N, 6.008525° W) and DAD2 (31.564447° N, 5.909513° W) covering Upper Dadès floodplain sections with alluvial fans formed by Dadès tributaries. The sub-catchment area of alluvial fan at DAD1 site is 22.73 km^2 with the gradient of 0.08. The sub-catchment of the fan at DAD2 site is much smaller: 2.95 km^2 and steeper with 0.28 gradient (Dłużewski et al., 2013; Rojan, 2019).

Sediment supply to the Upper Dadès river system is enhanced by scarce vegetation cover suppressed by semi-arid mountain climate and grazing (Mather and Stokes, 2018). Thus, tributary fans in the valley of Dadès River are extensive and often force the relocation of the main river channel. Fans are composed of coarse clastic sediments, mainly cobbles and boulders, with the size and shape depending on bedrock lithology and structure in the tributary catchment. The study area is mostly composed of Jurassic carbonate rocks (limestones, marlstones and dolomites), but Neogene conglomerates dominate at lower elevations (Carte Géologique du Maroc, 1990, 1993). The relief of the Upper Dadès catchment developed in Cenozoic through the collision of the African and European tectonic plates. Since Middle-Late Pleistocene, the area is subjected to low tectonic activity rates (Mater and Stokes, 2018).

Average annual precipitation along the Upper Dadès River ranges from 150 mm in the lower section of the valley (in Boumalne: Fig. 1) to 200 mm in the valley's upper section (in M'smerir: Fig. 1).

However, annual precipitation totals are very variable, and in the upper section of the valley can range from 50 to nearly 400 mm/year (data since 1963) (Dłużewski et al., 2013). Precipitation is highly seasonal with its majority falling in October-November and February-March (Fig. 2), which is reflected in the seasonality of discharge of the Dades River and its tributaries (Schultz et al., 2008). In the upper section of the Dadès River the average daily discharge is 3.5–4.5 m^3/s and in the lower part: 33 m^3/s (0.0218 m^3/s/km^2 of unit runoff from an area of 1525 km^2) (Fink and Knippertz, 2003; Schultz et al., 2008). However, all rivers in the study area present high variability of discharges related to episodic precipitation patterns typical for arid mountains (Fig. 2). In fact, not every year brings rainfall events sufficient for water flow in episodic tributaries of the Dadès River (Rojan et al., 2020).

Major floods, able to significantly transform the topography of Dadès floodplain and tributary fans, occur every ten years on average (Stokes and Mather, 2015). In the last decade, the strongest rainfall and flood in the study area occurred in November 2014, preceded by two smaller floods, earlier in the second half of 2014 (Fig. 2). During the flood of November 2014, 81.8 mm of rain fell during 49 h in the sub-catchment of DAD1 fan and 68.4 mm during 75 h in DAD2 sub-catchment. The maximum rainfall intensity was 59.2 mm/24 h and 6.8 mm/h at DAD1 and 43.2 mm/24 h and 8.2 mm/h at DAD2. This rainfall caused 11.6 m^3/s of peak discharge at the mouth of DAD1 tributary and 17.1 m^3/s at the

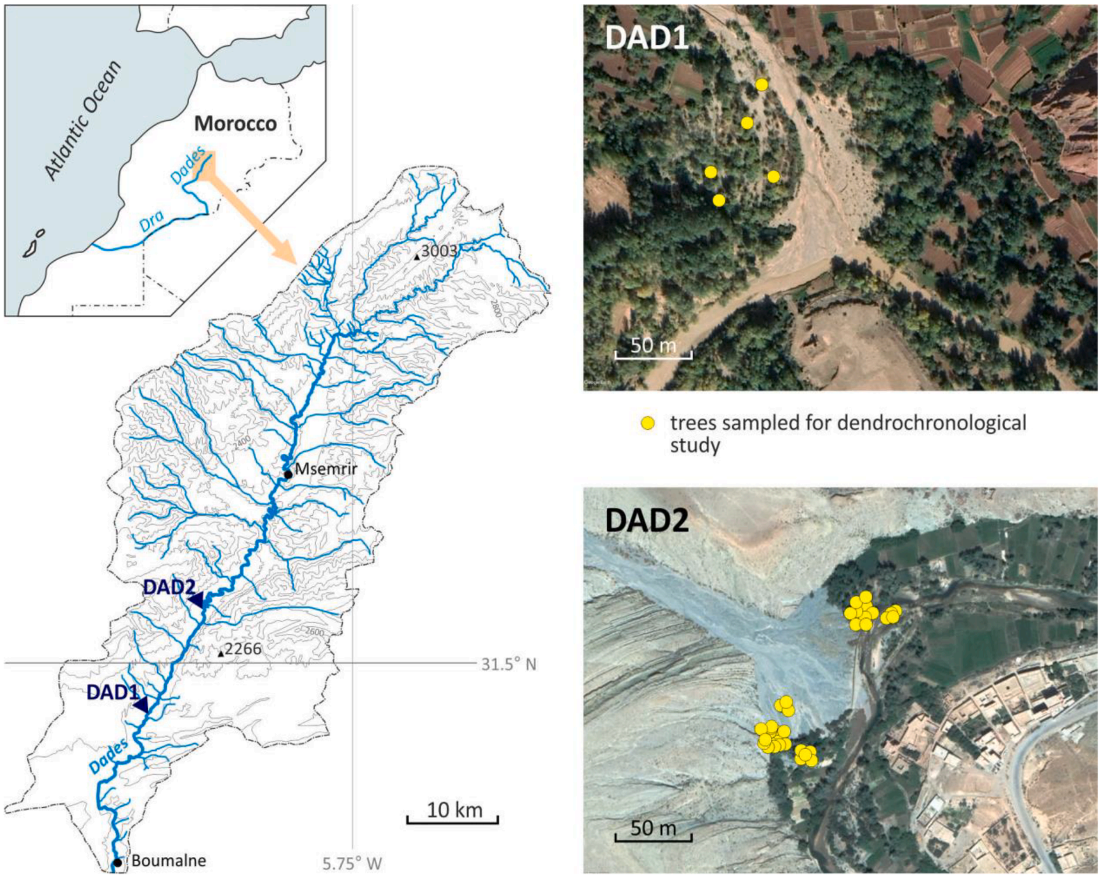

Fig. 1. Location of the study area, the catchment of Upper Dadès River. Location of DAD1 and DAD2 study sites in the Upper Dadès valley with the position of trees sampled on study sites.

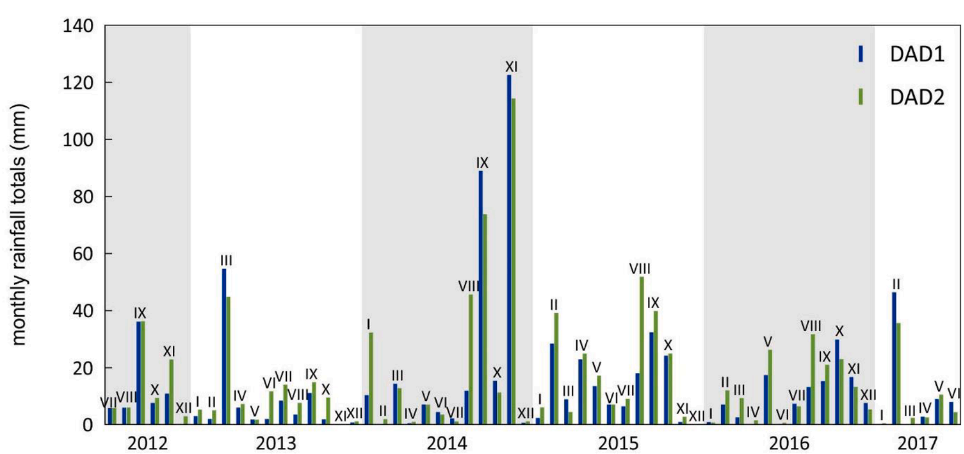

Fig. 2. Monthly rainfall totals for gauging stations located at DAD1 and DAD2 study sites from July 2012 to June 2017.

mouth of DAD2 tributary (Rojan et al., 2020). Both study sites, DAD 1 and DAD 2, are not only monitored hydrologically. In addition, after floods, observations are conducted in those areas in search of any changes in valley topography caused by fluvial erosion or accumulation. The observations after the November 2014 flood indicated significant amounts of freshly deposited sediments at sites DAD 1 and DAD 2, which proves that both sites were flooded at the time. Therefore, the flood of November 2014 was documented not only hydrologically (Fig. 2) but also with regard to relief changes.

3. Study methods

We analysed dendrochronological record of the 2014 flood on Dadès River to demonstrate the potential dual and opposite reaction of trees to floods in arid areas. For this purpose in autumn 2018 we used Pressler borers to collect samples (cores) from stems of 42 silver poplar trees (*Populus alba*) growing on the two sites under study: DAD 1 and DAD 2 (Fig. 1). We sampled trees with stems buried by debris transported during floods (Fig. 3), but we avoided heavily injured trees and trees with deformed stems. We collected cores from trees that grow in the areas of sediment deposition of the November 2014 flood. We recorded

Fig. 3. *Populus alba* trees growing in the valley of Upper Dadès River: a group of trees with stems buried by fresh alluvia of the 2014 flood (A) and an example of *Populus alba* sampled for dendrochronological analysis, also buried with the 2014 flood debris (B).

the position of individual trees with GPS and measured their distances from river banks.

Sampled cores were glued into wooden holders and then sanded with abrasive paper (250, 500 and 1000 grit size) to reveal the wood structure. Then, we measured the widths of individual tree rings using the LinTab measuring system. Obtained tree-ring curves were correlated using skeleton plot technique. We avoided data standardisation as age trend is not visible in analysed tree-ring curves. Raw chronologies for individual trees were recalculated to emphasise annual variability of tree-ring widths (year-to-year differences). For this purpose, we modified the procedure established by Nowacki and Abrams (1997), which allows calculation of per cent growth change (%GC). This indicator of growth changes is calculated for each ring as a per cent difference between the average ring width for ten subsequent years and average for ten preceding years:

$$\%GC = (M2 - M1)/M1 \times 100;$$

where %GC – percentage of growth change between the preceding ten years and subsequent 10, M1 – average ring width for the preceding ten years, M2 – average ring width for the subsequent ten years.

Formula proposed by Nowacki and Abrams (1997) is commonly applied in forest ecology for dating abrupt growth releases and growth reductions in longer periods. For this study, to calculate year-by-year growth changes, we use the same formula, but we use widths for single years instead of average widths for ten years. Thus, in the formula above we used ring width in the preceding year as M1 and ring width in the current year as M2. This modification allowed us to study trees' reaction to short environmental impulses, occurring only in one year, like floods.

Finally, we divided studied trees into two groups based on described calculations: trees that produced wider rings in 2015 and trees that produced narrower rings in 2015. We analysed the year following the flood of November 2014, because in High Atlas Mountains dormancy extends from summer to the beginning of spring (Kherchouche et al., 2019). Studied flood occurred after the 2014 growing season and could be recorded by trees only since next spring.

We calculated arithmetic means, standard deviations, and coefficients of variation for widths of rings developed by all trees each year, separately for both groups of trees as mentioned above and for the whole sampled population of trees. Studied trees are relatively young. Thus, statistical parameters were calculated only since 2005 (when over half of the trees were already growing), up to 2018 (year of sampling). Standard deviations and coefficients of variation (standardised measure of dispersion) allowed us to determine which group of examined trees has more consistent or heterogeneous tree-ring widths in individual years.

4. Results

The arithmetical mean of ring widths in studied trees is 8.07 mm. In 2015, following flood in November 2014, half of sampled trees (21 trees) developed rings wider than in 2014, before the flood. The other half of sampled trees presented opposite reaction and developed narrower rings (Fig. 4). At site DAD 1 three sampled trees developed wider rings and two narrower, and at site DAD 2 eighteen trees produced wider rings and nineteen narrower rings. The analysis with modified Nowacki and Abrams (1997) formula demonstrates that for 12 of 21 (57.1%) trees with increased ring widths in 2015, this was the most significant ring-width increase in their whole lives (in individual tree-ring chronologies) (Figs. 4 and 5). For 5 of 21 (23.8%) trees with decreased ring widths in 2015, this was also the most significant ring-width decrease in their whole lives (Figs. 4 and 5). For another seven trees, a decrease of ring width was found in 2015 compared to 2014, along with later increase of ring width in 2016. For these seven specimens, the 2016 increase was the most significant ring-width increase in their lives (Fig. 5). Altogether, calculations with the modified formula of Nowacki and Abrams (1997) revealed a group of 24 trees (57.1% of the sampled population) for which growth changes occurring in 2015–2016, potentially resulting from the 2014 flood, were the most significant changes of tree-ring widths in their whole lives and, thus in their individual tree-ring chronologies.

The arithmetic mean of the 2015 ring width in the whole population of 42 sampled trees is average, compared to arithmetic means for other, earlier or later years. However, arithmetic means calculated for 2015, for groups of trees with growth increases and decreases are significantly higher and lower than for other, earlier or later years (Fig. 6).

Data for the whole population of 42 sampled trees indicate that the average value of arithmetic mean in 2015 is accompanied by high standard deviation and coefficient of variation with increased level of both indicators maintaining in the following year (2016). In the group of 21 trees with wider rings in 2015, the standard deviation for 2015 is high, just like the arithmetic mean, but the coefficient of variation is at average level (Fig. 6). In this group of trees, arithmetic mean and standard deviation remain also increased next year (2016). In the group of 21 trees with narrower rings in 2015, the standard deviation for 2015 is low, just like the arithmetic mean, while the coefficient of variation is at an average level. The coefficient reaches its maximum, next year, in 2016, when the standard deviation is also high, but the arithmetic mean is average (Fig. 6).

5. Discussion

Various features of wood anatomy were, so far, used for dendrochronological dating of floods based on trees growing in river valleys. Yanowski (1983) distinguished flood rings, i.e. tree rings with enlarged vessels in latewood developed in years when floods occurred. Growth disturbances identified by Yanowski (1983) were accompanied by a slight increase in tree-ring width, which suggests, similarly as our study, that rates of radial growth of trees can increase due to floods. Astrade nad Bégin (1997) indicate different ways, in which a flood can be recorded by trees, depending on their species: *Quercus robur* develops anomalous structure of porous earlywood, while *Populus tremula* develops much narrower rings. In general, the primary indicator of flooding among coniferous trees is the reduction of tree rings associated

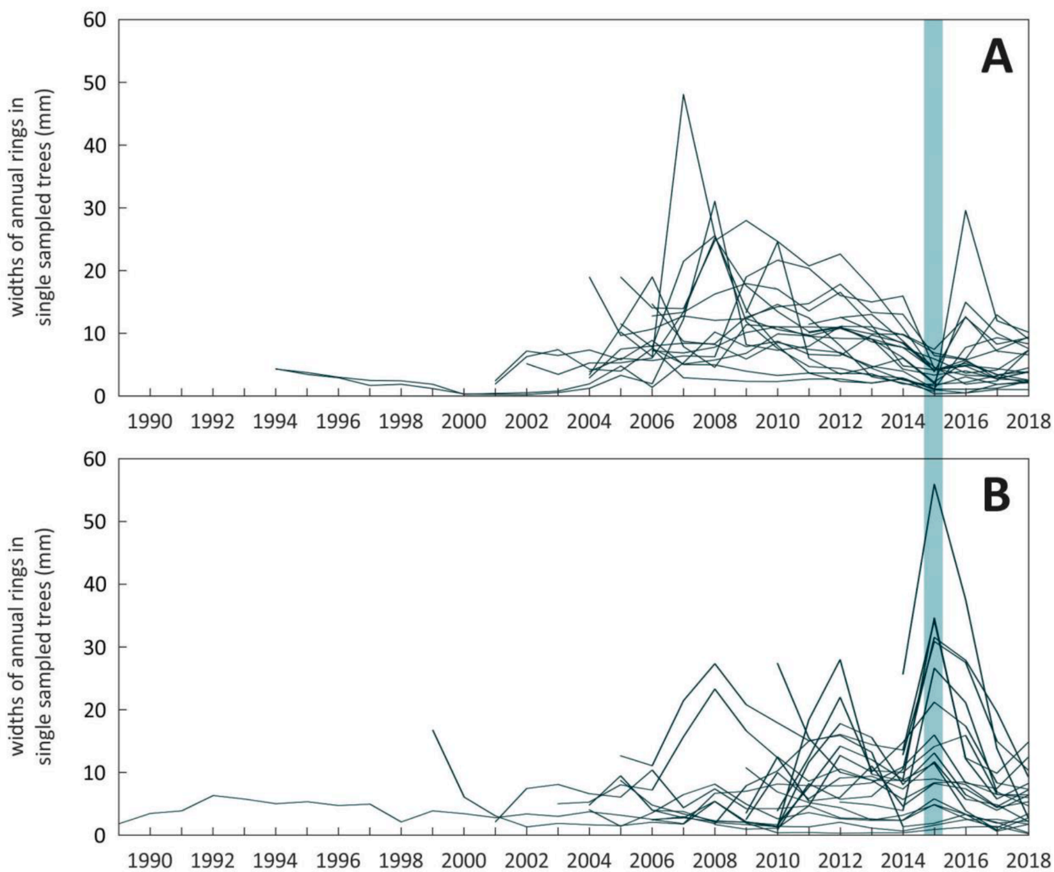

Fig. 4. Ring-width curves for trees under study divided into: trees, which developed narrower rings in 2015 (one year after the 2014 flood) (A) and trees, which developed wider rings in 2015 (B).

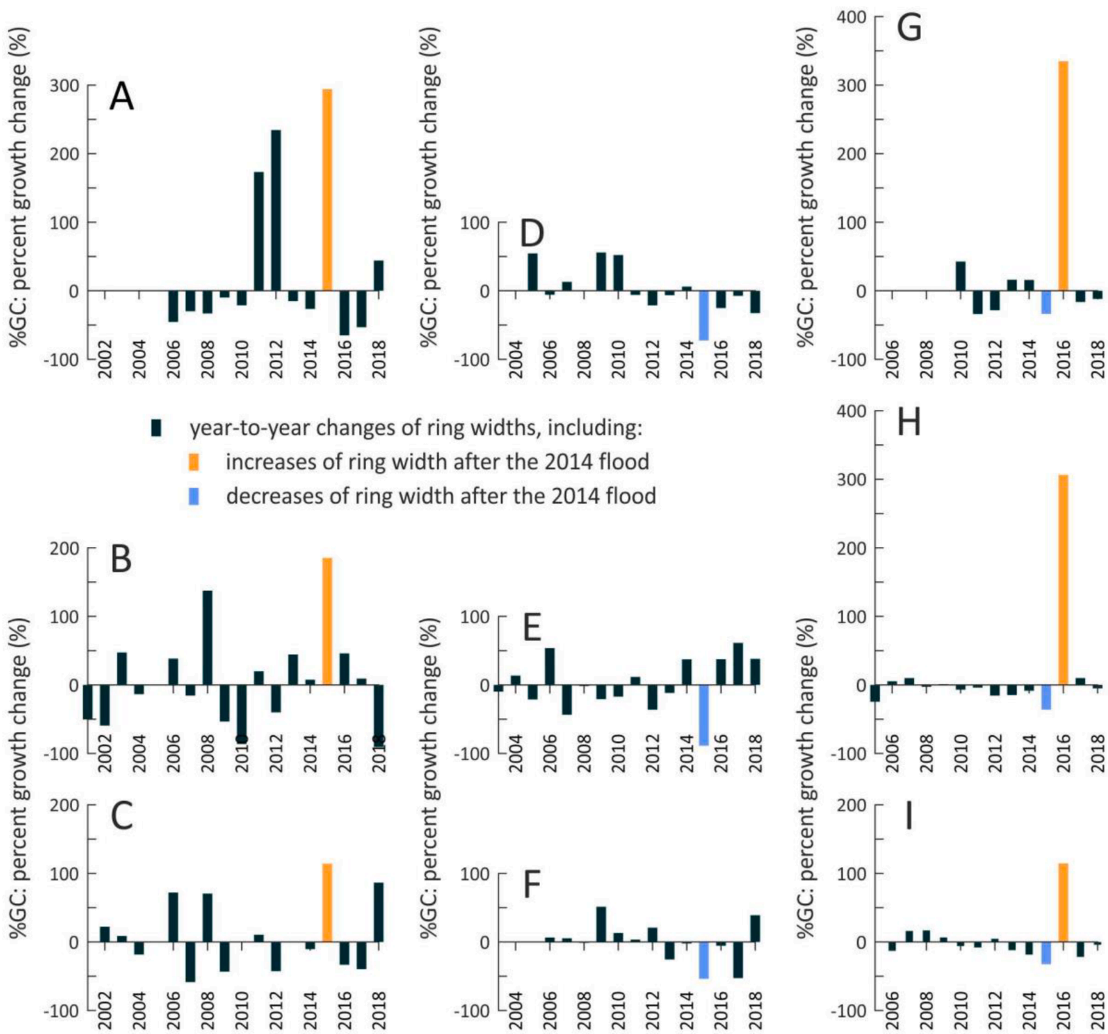

Fig. 5. Year-by-year changes in radial growth in selected trees from the samples population, including trees with particularly strong increases of ring width in 2015 (one year after the 2014 flood) (A, B, C), trees with particularly strong decreases of ring width in 2015 (D, E, F) and trees with decreases of ring width in 2015 but also strong increases of ring width in 2016 (G, H, I).

with reduction of tracheid size (Ballesteros-Cánovas et al., 2010a; Arbellay et al., 2012b). There are studies (Ballesteros-Cánovas et al., 2010b; Arbellay et al., 2012a; Wertz et al., 2013), which similarly to ours, demonstrate that deciduous trees also can record floods as ring reductions, as well as decreases in mean vessel size.

However, none of the previously published dendrochronological studies describes opposite, positive and negative, growth reactions of one group of trees of one species to the same flood event. This type of dual reaction potentially results from unique environmental impact floods exert in arid climates. Floods cause environmental stress through sediment deposition, which covers stems with debris and injures trees. Thus, tree roots are suddenly cut off from air access. However, floods also cause a sudden supply of water, improving water conditions of soil in arid areas, where, otherwise, water is scarce. While the formerly described flood stress can suppress growth in some trees, a supply of water can result in growth release in other specimens (Schäfer et al., 2017; Yu et al., 2019), in particular, if they remain uninjured and are not buried by alluvia. Depending on how the flood affects individual trees (negatively or positively), they can develop either strongly reduced or much wider rings.

Such clear reactions were found for the most of studied trees after the 2014 flood. As an episodic or seasonal remedy to water deficits in the study area, flooding explains the strong positive growth response of the half of trees under study. Simultaneously, the 2014 flood caused extensive accumulation of fresh alluvia on the Dadès floodplain and tributary fans (Rojan et al., 2020). Stems of numerous trees (Fig. 3), including sampled ones, were buried with sediments. Although none of the sampled trees was injured, stress caused by alluvia deposition was probably strong enough to cause growth reduction in half of the sampled population. A similar phenomenon was described, among others, by Strunk (1997), who demonstrated that trees buried with material from debris flows developed reduced tree rings.

The phenomenon of opposite growth reaction of trees found for the 2014 flood on Upper Dadès River can be compared to previous studies on the influence of other environmental factors on the radial growth of trees. Zielonka (2010) described a positive growth reaction of spruce and larch trees, which survived an event of strong wind in the Carpathian Mountains, in 2004 (trees fell over 12,600 ha), and negative growth reaction of specimens which were injured during the same wind event. Positive growth reaction was related to improved light conditions, as most trees fell during the wind episode (Zielonka et al., 2010), similarly to improved water conditions in the studied case of flood in arid mountains. In general, Zielonka et al. (2010) describes the environmental event with an incremental effect similar to flood event described in this paper. These are not isolated examples, as very often, the death of adjacent trees provides a positive growth impulse for surviving specimens (Cherubini et al., 1996; Hanson and Lorimer, 2007). Similar effects were observed in studies on the growth response of trees

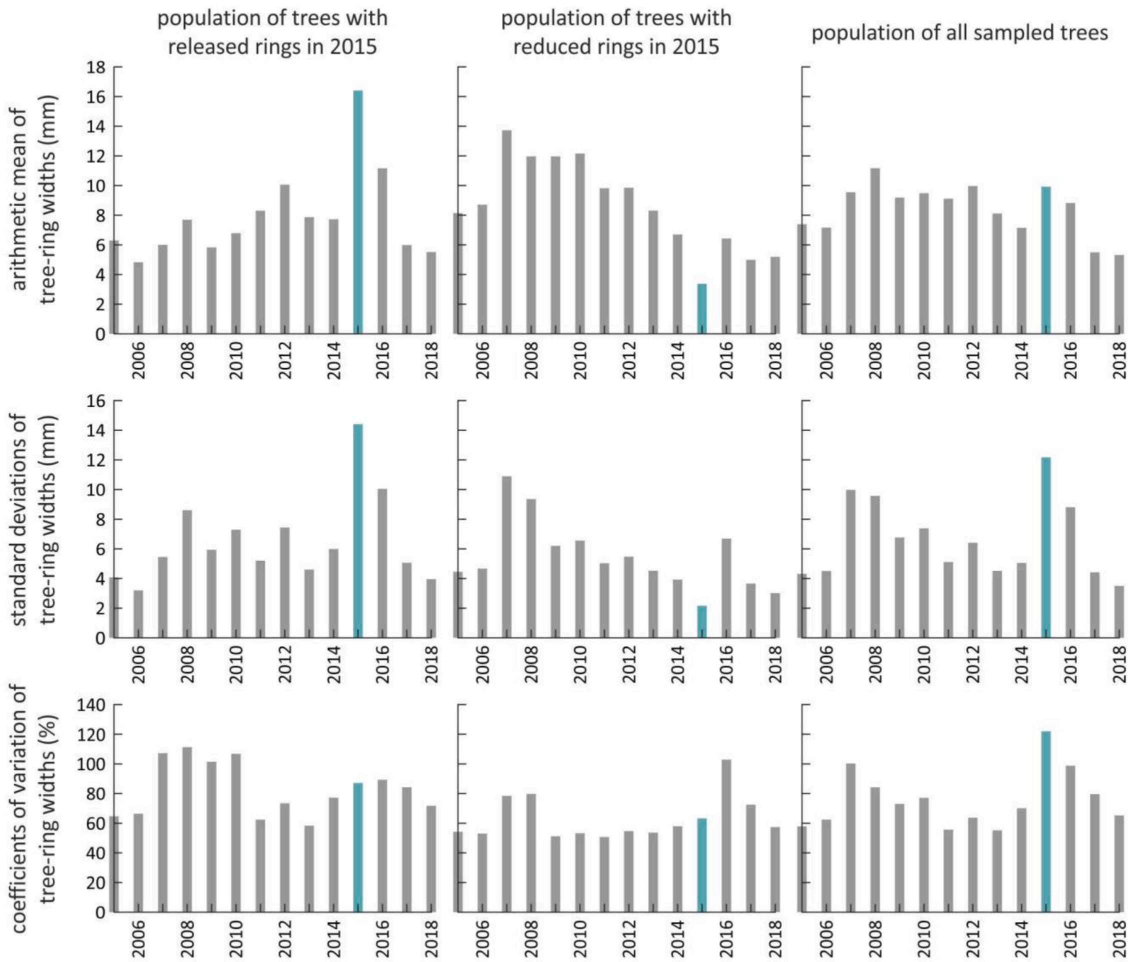

Fig. 6. Arithmetic means, standard deviations and coefficients of variation for widths of rings produced by trees in each year, including indicators calculated for the subpopulation of trees with growth release in 2015, the subpopulation of trees with growth reduction in 2015 and indicators calculated for the whole population of sampled trees.

to debris flows (Malik and Owczarek, 2009; Stoffel and Hitz, 2008). Debris flows often eliminate only part of trees and injure some of them. For example, trees growing at the edge of a forest, bordering debris flow track develop wider annual rings as trees growing on the track are often fallen by transported debris. On the other hand, trees growing directly along the track can be injured and develop reduced tree rings (Malik and Owczarek, 2009).

In the study conducted along Upper Dadès River it is unique that some of sampled trees developed strongly reduced rings in 2015, immediately after the flood, and extremely wide rings next year, in 2016 (Figs. 4 and 5). This effect is also reflected in statistical indicators calculated for all trees with ring reduction in 2015 (Fig. 6). Growth reduction in 2015, directly after the flood in November 2014, may result from high environmental stress exerted on trees buried by alluvia and prolonged inundation of stems and root systems. In 2016 groundwater level dropped enough to release radial growth but was still high enough to support intensified radial growth.

Dendrochronological record of floods in high-mountains of arid climatic zone identified in this study can potentially aid future flood reconstructions in similar areas. However, long-term reconstruction would be possible only if there are older trees available on the floodplain than those in the Dadès River valley. Tree age is the main issue, because in arid areas, the occurrence of trees is very limited, and they are a valuable and continuously exploited resource for local communities. Hence, trees in areas such as Dadès River catchment are usually young and do not allow for reconstructing older floods. Besides, floods of different magnitudes can be recorded by trees in a different way. A flood of much larger magnitude than studied flood of November 2014 can deposit more debris and, thus, ring reduction could outnumber growth releases. On the other hand, smaller flood could deliver less material, not enough to bury tree stems. Then trees would produce mainly wider rings due to increased water supply. Finally, a particularly small flood could not be recorded by trees at all.

Results obtained for the 2014 flood on the Upper Dadès River show that simple calculation of arithmetic means of ring widths for all sampled trees can obscure the response of trees to an environmental impulse. In particular, partially positive and partially negative reaction of trees (half of them produced wider and another half narrower rings) can be erased (Fig. 6). This is a potential source of errors in environmental analyses based on tree rings., as averaging ring widths for each year to develop chronologies is a generally accepted dendrochronological research procedure (Alestalo, 1971; Schweingruber, 1988). However, our study also demonstrates that the occurrence of environmental impulses resulting in dual, opposite growth reaction of trees, can be revealed from standard deviations and coefficients of variation of tree-ring widths. In this study, both these parameters are exceptionally high in 2015, one year after the flood (Fig. 6). This indicates that the arithmetic mean is not representative for the studied trees, and that the response of trees to strong environmental impulse differs significantly and divides them into two groups reacting opposite to the same flood. In such cases, by checking only average ring widths for the whole sampled population, one can overlook a strong environmental event, which severely differentiates the growth reaction of trees.

6. Conclusions

Large floods in high-mountain valleys of the dry climatic zone can cause dual, opposite growth reaction among affected trees. This dual opposite reaction can be an indicator for past floods. In order to indicate the opposite reaction of trees, the following procedure should be followed:

- collecting cores from trees affected by floods, i.e. growing on the floodplain and buried with sediments,
- measuring tree ring widths in sampled cores,
- calculating per cent growth change year after year (%GC) as described in the Methods section of this manuscript,
- dividing sampled trees into two groups (first: trees producing narrower rings than a year before, second: trees producing wider rings than a year before) for each individual calendar year separately,
- checking established groups of trees with arithmetic means, standard deviations, and coefficients of variation to determine which group has more consistent or heterogeneous tree-ring widths in individual calendar year separately,
- outlining years with opposite growth reaction of trees as years with past floods.

Results demonstrate that floods in high mountains of the arid zone belong to a group of environmental factors which can affect the growth of trees in two ways at the same time. For some trees they can cause release of ring width and for other trees suppression of ring width. This type of tree-ring record is typical for environmental factors which can be at the same time beneficial for trees and act as a strong stress factor. Floods supply water in arid areas where moisture is usually scarce, but floods bury stems with sediments, suppress root systems and injure trees. Due to this dual, opposite impact, environmental impulses such as floods (but also strong winds, debris flows, snow avalanches, etc.) can be obscured in dendrochronological record, if only arithmetical means are used as a basis for chronologies. In a tree-ring chronology based on average ring widths the effect of studied 2014 flood will be invisible. Thus, the occurrence of this event will be omitted in palaeohydrological reconstruction based on tree rings. This study shows that arithmetical means can be unrepresentative for tree-ring anomalies related to floods in arid areas. Therefore, to merely average ring widths, without checking the detailed structure of the dataset, in particular indicators of dispersion (deviations and variations) for ring widths, can lead to underestimation of flood frequency and magnitude, and, also, flood hazard and risk.

CRediT authorship contribution statement

Ireneusz Malik: Conceptualization, Methodology, Writing - original draft. **Maciej Dłużewski:** Funding acquisition, Methodology. **Joanna Rotnicka:** Visualization. **Małgorzata Wistuba:** Writing - original draft. **Kazimierz Krzemień:** Validation. **Andrzej Muszyński:** Formal analysis. **Elżbieta Rojan:** Investigation. **Albert Ślęzak:** Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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